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♦ The AnyMedia® Access System—Providing Solutions for Distribution and Network Independence

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Today's network providers face a significant challenge in selecting and deploying access solutions that enable them to compete in an increasingly unpredictable and dynamic market. They must manage the uncertain interplay between the demands for circuit-based and packet-based services and, at the same time, avoid the possibility of being stranded with large unrecoverable investments in outmoded or incompatible infrastructure. The equipment deployed must ensure adequate capacity to support a complete set of applications and must maximize economies of scale. In response to these needs, Lucent Technologies has developed the AnyMedia® Access System, a platform for access network solutions supporting a full complement of telephony and broadband data services via standard, open network interfaces. This new fifth-generation access system builds on Lucent's heritage of high-reliability access network elements and leverages Lucent's Access Interface Platform (AIP) technology. The AIP is shared with the 5ESS® line units, AnyMedia Access Interface Units (AIUs), and other products to provide integrated voice and data access facilities for 24-channel and 30-channel markets. The new system can serve as a gateway between the circuit-switched telephony network and the ATM networks that transport telephony services over standard ATM format. We present here an overview of the AnyMedia Access System hardware and software architectures, system applications, and capabilities.

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The Access Challenge

In the context of electronic communications, *access* is the connecting of end users to their desired networks. *Access networks* are the means of connecting the end-user equipment—such as a telephone or a personal computer—to the *service networks*, which provide the switches and transmission facilities required for useful connections. The first access networks consisted of pairs of wires from users' telephones to a switch. As the penetration of telephony grew, the meaning of access networks grew to include *access nodes*, systems that multiplex and perhaps concentrate a set of user connections prior to presenting them to the switch. A new segment of the communications industry was born to provide these multiplexers/concentrators—*digital loop carrier (DLC)* systems—for the subscriber loop. Today, access systems serve a variety of user connections, including "plain old telephone service" (POTS), high-speed digital subscriber line (DSL) interfaces, cable modems, wireless terminals, and even fiber to the home (FTTH). The end users may be connecting to different types of networks, such as the public switched telephone network (PSTN), enterprise networks, or the global Internet (**Figure 1**). The accommodation of these various options by equipment providers has become an increasingly complex task.

As a further challenge to the access equipment

Panel 1. Abbreviations, Acronyms and Terms

100BaseT—IEEE 802.3 local area network 100-Mb/s Fast Ethernet standard
10BaseT—IEEE 802.3 100-meter local area network using Ethernet twisted-pair cable
802.3—IEEE link-level standard for carrier sense multiple access/collision detection (CSMA/CD) LANs
AAL—ATM adaptation layer
ABM—ATM buffer manager
ADSL—asymmetrical digital subscriber line
AFM—ATM feeder multiplexer
AIP—Access Interface Platform (Lucent)
AIU—Access Interface Unit (Lucent)
ANSI—American National Standards Institute
AP—application pack
ATM—asynchronous transfer mode
BB—broadband
BRI—basic rate interface
CAC—connection admission control
CBR—constant bit rate
CC—communications channels
CIT—craft interface terminal
CIU—communications interface unit
CLP—cell-loss priority
CO—central office
COMDAC—common data and control
CTU—craft/test unit
DEMUX—demultiplexer
DLC—digital loop carrier
DS0—digital signal level 0, transmission rate of 64 kb/s (1 channel) in time division multiplex hierarchy
DS1—digital signal level 1, transmission rate of 1.544 Mb/s (24 64-kb/s channels) in time division multiplex hierarchy
DS3—digital signal level 3, transmission rate of 44.736 Mb/s (672 64-kb/s channels) in time division multiplex hierarchy
DSLAM—digital subscriber line access multiplexer
DSL—digital subscriber line
DSP—digital signal processor
DSX-1—digital cross connect 1; electrical format specification for DS1 signals transmitted over short distances
E1—European signal rate of 2.048 Mb/s (30 64-kb/s channels)
E3—European signal rate of 34.368 Mb/s (480 64-kb/s channels)
EAIU—Access Interface Unit Expansion
EIA—Electronic Industries Association
EOC—embedded operations channel
FITL—fiber in the loop
FTP—file transfer protocol
FTTC—fiber to the curb
FTTH—fiber to the home
GSI—graphical system interface
HDLC—high-level data link control
HDSL—high bit-rate DSL
HDT—host digital terminal
HFC—hybrid fiber-coax
I/O—input/output
IAD—integrated access device
IEEE—Institute of Electrical and Electronics Engineers
ILMI—integrated local management interface
INA—integrated network access
INE—Intelligent Network Element (Bellcore/Telcordia)
inetd—Internet services daemon (Hewlett Packard)
IP—Internet protocol
ISDN—integrated services digital network
ITU-T—International Telecommunication Union—Telecommunication Standardization Sector
LAN—local area network
LDS—local digital switch
LEC—local exchange carrier

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manufacturers, there are different types of network providers, each with a unique set of goals. Incumbent network providers face the challenge of evolving their access networks to support continued growth in traditional services and the growing momentum to transition from circuit-based to packet-based applications. New entrants face the challenge of competing against incumbents and against other new entrants using access networks built from a variety of access technologies that are typically optimized per application. A mix of leased wireline facilities and wireless infrastructure may be used to maximize the ability to serve a high percentage of customers while minimizing costs and time to deployment, driven by the goals and resources of the service providers. Regardless of the distribution options deployed for each customer, the service provider faces the additional challenge of providing an offer with a consistent feature set, user inter-

Panel 1. Abbreviations, Acronyms and Terms (continued)

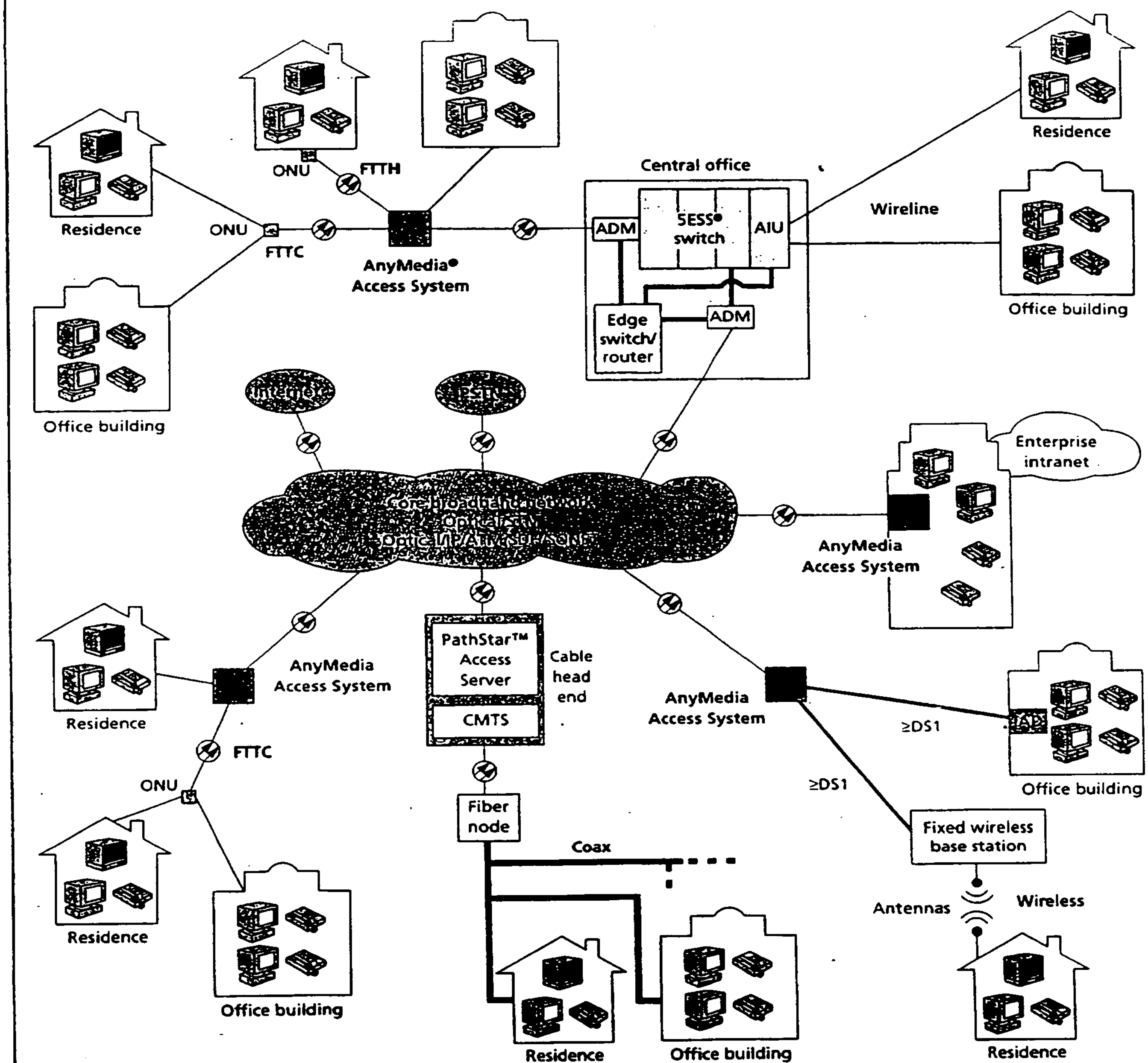
MDS-2—metallic distribution shelf 2
MSDT—Multi-Service Distant Terminal
MUX—multiplexer
nrt—non real time
$N \times$ DS0—N concatenated DS0 channels, where $1 \leq N \leq 24$
OAM&P—operations, administration, maintenance and provisioning
OAP—optical applications pack
OC-3—optical carrier digital signal rate of 155 Mb/s in a SONET system
OC-12—optical carrier digital signal rate of 622 Mb/s in a SONET system
ONU—optical network unit
PCM—pulse-code modulated/modulation
PLD—programmable logic device
PON—passive optical network
POTS—"plain old telephone service"
PPM—periodic pulse metering
PPP—point to point protocol
PSTN—public switched telephone network
PVC—permanent virtual circuit
QoS—quality of service
RAIU—Access Interface Unit Remote
RAM—random access memory
RISC—reduced instruction set computer
ROC—remote operations channel
ROOM—real-time object-oriented modeling
RS-232—recommended standard 232; TIA/EIA standard for computer/peripheral transmission
RT—remote terminal
rt—real time
SAR—segmentation and reassembly
SDBAS—Switched Digital Broadband Access System (Lucent Technologies/Broadband Technologies)
SDH—synchronous digital hierarchy
SNMP—simple network management protocol
SONET—synchronous optical network
STM-1—synchronous transfer mode optical signal at 155 Mb/s
STM-4—synchronous transfer mode optical signal at 622.08 Mb/s
SVC—switched virtual circuit
T1—terrestrial (North American) facility to transport signal at primary rate of 1.544 Mb/s (24 64-kb/s channels)
TCP/IP—transmission control protocol/ Internet protocol
TDM—time division multiplexing
TIA—Telecommunications Industry Association
TL1—Transaction Language 1 (Bellcore/Telcordia)
TMC—time slot management channel
TMN—telecommunications management network
TSI—time-slot interchanger
UART—universal asynchronous receiver-transmitter
UBR—unspecified bit rate
UNI—user-network interface
VBR—variable bit rate
VC—virtual channel
VCC—virtual channel connection
VCI—virtual channel identifier
VDSL—very high speed DSL
VF—voice frequency
VoIP—voice over IP
VP—virtual path
VPC—virtual path connection
VPI—virtual path identifier
VRT—virtual remote terminal
WDM—wavelength division multiplexing
xDSL—any of various DSL technologies

face, and quality of service (QoS) on a regional, national, or international basis.

As access options and core networks evolve, network providers can protect their investments by deploying access equipment whose capabilities for distribution (toward the end user) and the network (toward the core/backbone) can evolve independently. This can be achieved by deploying a new generation of access solutions, such as the AnyMedia® Access System, that enable true network flexibility.

Services

The end user may demand multiple types of service interfaces, including voice frequency (VF), integrated services digital network (ISDN) basic rate, any of various digital subscriber line technologies (xDSL), or 10/100BaseT Ethernet. End users may also demand a variety of formats such as Internet protocol (IP), frame relay, and asynchronous transfer mode (ATM) to carry this service mix. Access equipment should be configurable to support simultaneous deployment of wireline (POTS, ISDN, xDSL, and



ADM – Add/drop multiplexer
AIU – Access Interface Unit
ATM – Asynchronous transfer mode
CMTS – Cable modem termination system
DS0 – Digital signal level 0, transmission rate of 64 kb/s (1 channel) in time division multiplex hierarchy
DS1 – Digital signal level 1, transmission rate of 1.544 Mb/s (24 64-kb/s channels) in time division multiplex hierarchy

FTTC – Fiber to the curb
FTTH – Fiber to the home
IAD – Integrated access device
IP – Internet protocol
ONU – Optical network unit
PSTN – Public switched telephone network
SDH – Synchronous digital hierarchy
SONET – Synchronous optical network

STM – Synchronous transfer mode
xDSL – Any of various digital subscriber line technologies

Coax line
Optical fiber line
Twisted pair (DS0/xDSL)

Figure 1.
Lucent's network vision for access.

T1/E1), wireless, fiber, and other distribution media options. The equipment should maximize reuse of common technology and transport infrastructure between circuit-switched and packet-switched (IP or ATM) services. This can be achieved through conformity of cross-product platform technologies and developing product families. In addition, access solutions must support exchange of traffic between each end user and the PSTN, the global Internet, and enterprise networks. While addressing all required interfaces and available media, network providers need a platform that leverages their investment in feature development, deployment, and marketing, as well as operations, administration, maintenance, and provisioning (OAM&P).

The AnyMedia Access System has been designed to accommodate these service needs. On the distribution side, the AnyMedia system terminates POTS, ISDN, and T1/E1 lines, as well as a variety of xDSL technologies. Through the AnyMedia system—and sibling products built on common platform technology—data may be transported back to the network over a mix of circuit infrastructure types, such as traditional, ATM, and IP.

Access History—Lucent Perspective

Historically, access has supported only narrowband technology, such as 64-kb/s POTS services. Even today, the predominant mode of connecting end users to their networks is a simple line unit in a switch that serves subscribers via copper pairs. Remote access units use networks of fiber multiplexers to transport their traffic between multiple locations using optical facilities. One of these locations will typically house a Class 5 switch, such as the 5ESS® Switch. The Class 5 switch is a member of a hierarchy of switches that, together with the interexchange carrier transmission systems, make up the global switched telephone network.

The SLC®-96 subscriber loop carrier, the first DLC, was developed by Bell Labs in the 1970s to support 96 64-kb/s channels. It was revolutionary in that it significantly reduced the number of lines that connected directly to the central office (CO), often via sets of massive cables. Instead, a group of lines could be terminated at a remote location, then aggregated, and their signals be transmitted to the CO over DS1 trunks (each carrying 24 64-kb/s channels) using a unique signaling interface between the remote terminal (RT) and the switch. TR-08,[1] the first Bellcore standard for DLC switch interfaces, was modeled after the SLC-96 switch interface. Lines that were a short distance from the CO could still be terminated directly on the switch.

The SLC Series 5 Carrier System, Lucent's second generation DLC, was built on the principles used in the original SLC-96 system. The SLC Series 5 Carrier System is a full-service vehicle for telephony and 64-kb/s data solutions. Systems are configured as dual channel banks, since each contains two 96-line subsystems. This is accomplished in the same space as a single 96-line SLC-96 system. SLC Series 5 dual channel bank systems are available in either CO or remote configurations. This DLC is most suited for small-to-medium-size business and residential serving areas such as college campuses or strip malls. The SLC Series 5 Carrier System offers low start-up costs, and fits into customer premises locations or small community service cabinets. This system can connect to multi-vendor switch platforms utilizing a GR-303[2] interface between the RT and the CO in addition to the TR-08 interface.

The SLC-2000 Access System is Lucent's third-generation access system. Its high-density design places four times as much capability into the same frame as earlier DLC systems. The SLC-2000 Access System is a DLC system that provides a full complement of telephony services—including POTS, ISDN, and business and residence customer services—and offers mixed metallic and fiber distributions. For fiber distribution, the SLC Series 5 and SLC-2000 carriers support Lucent's Multi-Service Distant Terminal (MSDT) as the optical network unit (ONU). These carriers pioneered the use of single-fiber bidirectional connections in order to serve 24 VF channels to each ONU. Traditional channel units, which would have been located in the SLC-2000 distribution shelf for metallic distribution, are now remotely located at the MSDT as a fiber-to-the-curb (FTTC) application. Both TR-08 and GR-303 interfaces are provided by the DLC system for flexibility in configuring up to 1152 lines in a fiber-in-the-loop (FITL) configuration.

In the early 1990s, residential and small-business customers became interested in broadband and interactive services. At the time, two types of access systems were developed to meet the needs of Lucent's (then AT&T's) customers. The first was the hybrid fiber-coax HFC-2000® broadband access system, providing an economical access link to a combination of narrowband telephony and broadband services—the latter ranging from video-on-demand to home shopping and interactive music. The HFC-2000 system used a common coaxial cable for broadband multimedia and narrowband telephony services in the last mile of the access network and fiber optics to connect the last mile to a host DLC and a cable head end. This combination had the capacity needed for a broadband system and—given the installed base of telephony cables and cable TV coax—copper is still considered by many as the most cost-effective distribution means for residential systems.

The second type of access system developed in the early 1990s, the Switched Digital Broadband Access System (SDBAS) from Lucent along with Broadband Technologies, Inc., offered both conventional services and new broadband multimedia services over an integrated system based on ATM. SDBAS was deployed by several carriers for FITL applications serving a mix of residential and small business end users. SDBAS's strength was its end-to-end high-speed transport architecture, designed to support a diverse mix of narrowband, wideband, and broadband services over a single access network.

Access Applications for Basic Telephony and xDSL Services

Figure 2 illustrates deployment of AnyMedia Access Systems in traditional configurations that might be used by incumbent local exchange carriers (ILECs). In such applications, the AnyMedia Access System provides an integrated solution for both POTS and DSL services in a single system. For incumbents, it allows the upgrade of an existing AnyMedia POTS system by adding DSL services to their portfolio. New service providers can enter the market while deferring investment in as-yet-unused services. The integrated shelf gives both types of network providers a single solution with a clear migration path from circuit-based services to packet-based services.

In current applications, voice services are transported back to the PSTN network over DS1 (1.544-Mb/s) or E1 (2.048-Mb/s) rate feeders using GR-303 or V5[3,4] interfaces to a Class 5 switch. xDSL services are transported back to the backbone ATM network. The POTS twisted pairs terminate on a POTS application pack (AP), an application-specific circuit pack. Each POTS AP supports 32 lines at digital signal level 0 (DS0), a rate of 64 kb/s. After formatting by a common-data-and-control (COMDAC) circuit pack (a shelf controller card) these DS0s are packaged into the feeder DS1/E1 format for transport to the switch. DS1/E1s are also received from the switch, demultiplexed to DS0s, and then formatted by the COMDAC for transport to the end user by the POTS AP. xDSL services are terminated on DSL APs. In the current release, each DSL AP supports four terminations. Future releases will support up to eight terminations on one AP. After formatting and processing these cells as needed by the ATM feeder multiplexer (AFM) pack, the aggregated data bandwidth is transported toward the ATM backbone over an ATM DS3 (44.736-Mb/s) line.

Platforms, Commonalities, and AIU Relations

Both the 24-channel and 30-channel DLC versions of the AnyMedia Access System (**Figure 3**) are built atop Lucent's Access Interface Platform (AIP). The AIP provides a set of assets that can be used in service node and access node applications to provide services to subscribers. These include narrowband services (POTS, ISDN, coin, periodic pulse metering [PPM], and other special services) as well as broadband services such as asymmetrical digital subscriber line (ADSL). AIP assets provide:

- Very low-cost line terminations via economies of scale for components and via high circuit densities (up to 640 lines per shelf),
- Common solutions for emerging broadband services,
- High-speed cell/packet transmission paths, and
- High reliability.

By leveraging the assets that the AIP provides, the AnyMedia Access System has been able to achieve shorter development cycles than in previous generation products, as well as a high degree of interchangeability and reusability with other products. This means

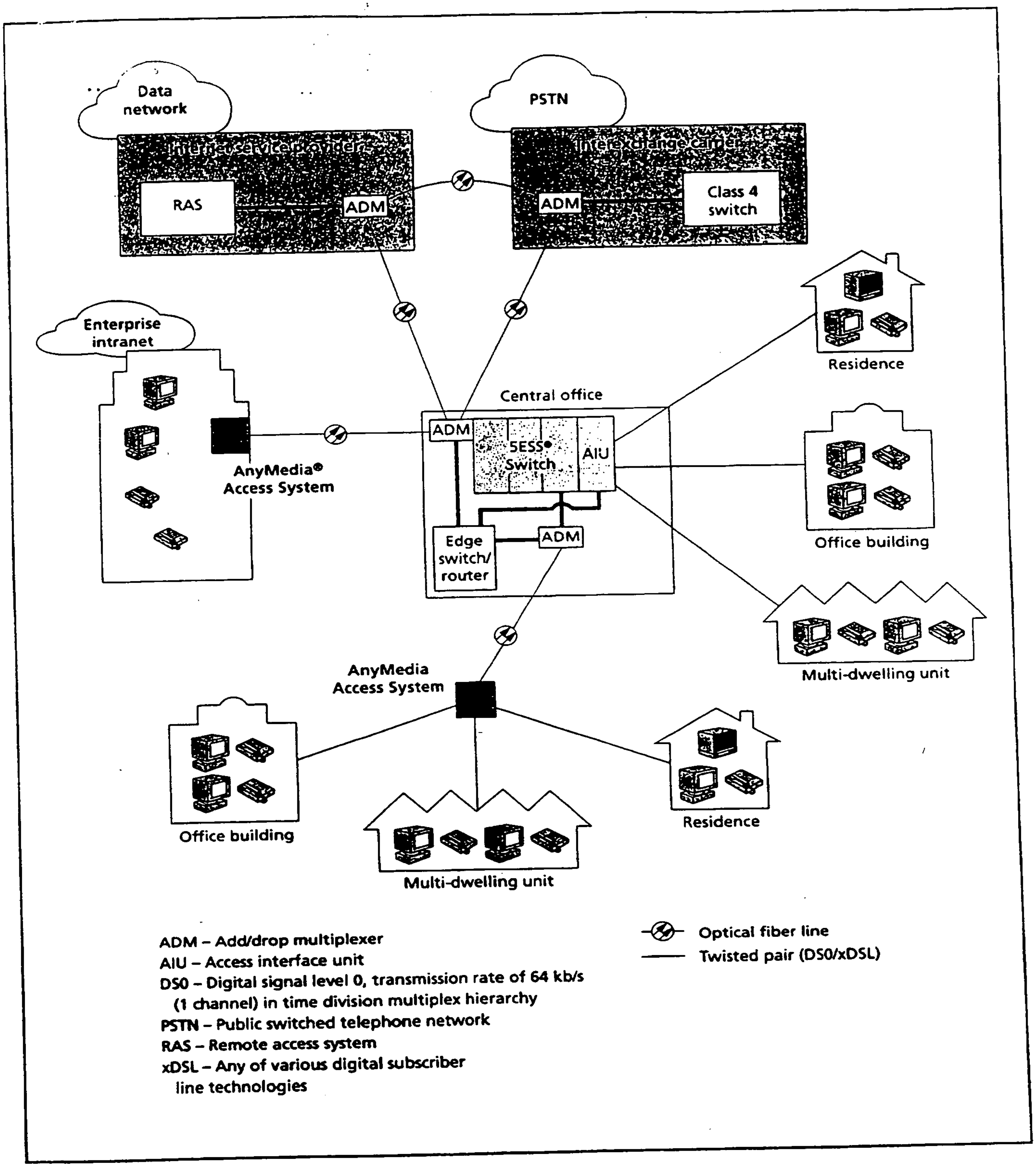


Figure 2.
Traditional access applications for voice and data.

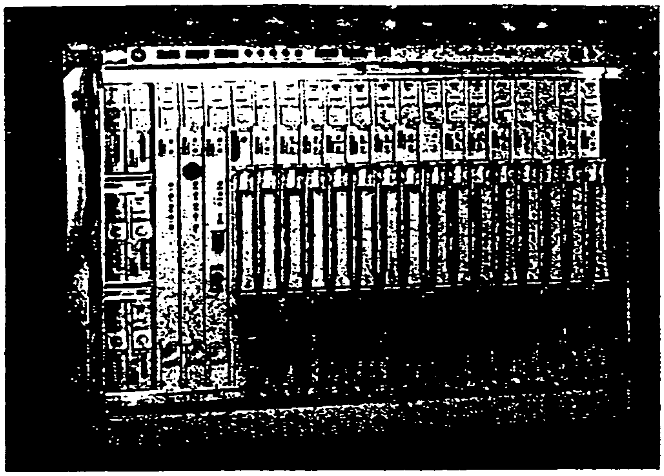


Figure 3.
A 24-channel AnyMedia® shelf built atop the Access Interface Platform.

that new features can be added to the AnyMedia product more quickly using the AIP than if they were individually developed for each product. The AIP hardware assets currently used in the AnyMedia Access System include:

- A narrowband backplane,
- A 32-line POTS AP,
- A 16-line American National Standards Institute (ANSI) ISDN AP,
- A 12-line European Telecommunications Standards Institute ISDN AP,
- Broadband backplane(s),
- A 25-MHz broadband bus interface device,
- An ATM feeder multiplexer, and
- Quad ADSL APs.

Other items are in the planning stages for future deployment, including combination POTS/quad DSL (G.Lite[5]) APs.

AIP technology is the core for other line-side distribution products such as the PathStar™ Access Server, the 5ESS line units, and the AnyMedia Access Interface Unit (AIU), along with its sibling products—the Access Interface Unit Remote (RAIU) for 30-channel markets and the Access Interface Unit Expansion (EAIU) for the 24-channel market. Other than hardware and software, the products built on AIP technology share many common attributes. They support multiple types of access distribution technologies, such as metallic (including xDSL), fiber (for FTTL), coaxial cable, and radio frequency (for wireless).

Access Economics

Figure 4 compares the cost of access for network providers deploying different access technologies in residential applications. Access technologies are plotted as relative cost versus peak bandwidth (Mb/s). For each technology, the cost to the service provider includes the price of the customer premises equipment, the incremental price of equipment at the RT site (if any), and the incremental price of a Class 5 switch or edge router/switch as needed. The incremental cost of upgrading the plant is included, where applicable. Where appropriate, the AnyMedia Access System has been used as the DLC and/or digital subscriber line access multiplexer (DSLAM). The comparison focuses primarily on the incremental cost of adding data services. For example, for VF there are two cases plotted. The first assumes that a subscriber will use his/her primary line for Internet/intranet access. Therefore, the cost includes the market price of a 56-kb/s modem without the cost for the actual telephone line. For the second VF case, it is assumed that the end user subscribes to an additional POTS line dedicated to Internet/intranet access. The total cost includes the cost of the 56-kb/s modem, the incremental price at the RT and/or switch, and the cost of installing a second line.

The ISDN and DSL economic models are very similar to that used for VF. Two types of DSL service are modeled: full-rate ADSL (8 Mb/s downstream and 640 kb/s upstream) and G.Lite DSL (1.5 Mb/s downstream and 640 kb/s upstream). For both cases, the same DSLAM equipment based on the AnyMedia system is assumed. For the case of fixed wireless, both stationary beam and steered beam technologies are modeled. Both types of fixed-wireless system models are based on Lucent's Airloop® technology.

The cable modem and FiberVista cases are plotted two ways. The higher cost includes the cost of upgrading existing outside plant to support high-speed services, as well as the cost of the data terminal equipment at the end-user site, the hub, and the head end. The lower cost assumes no need for upgrade. FiberVista, a proposed technology extending hybrid fiber-coax

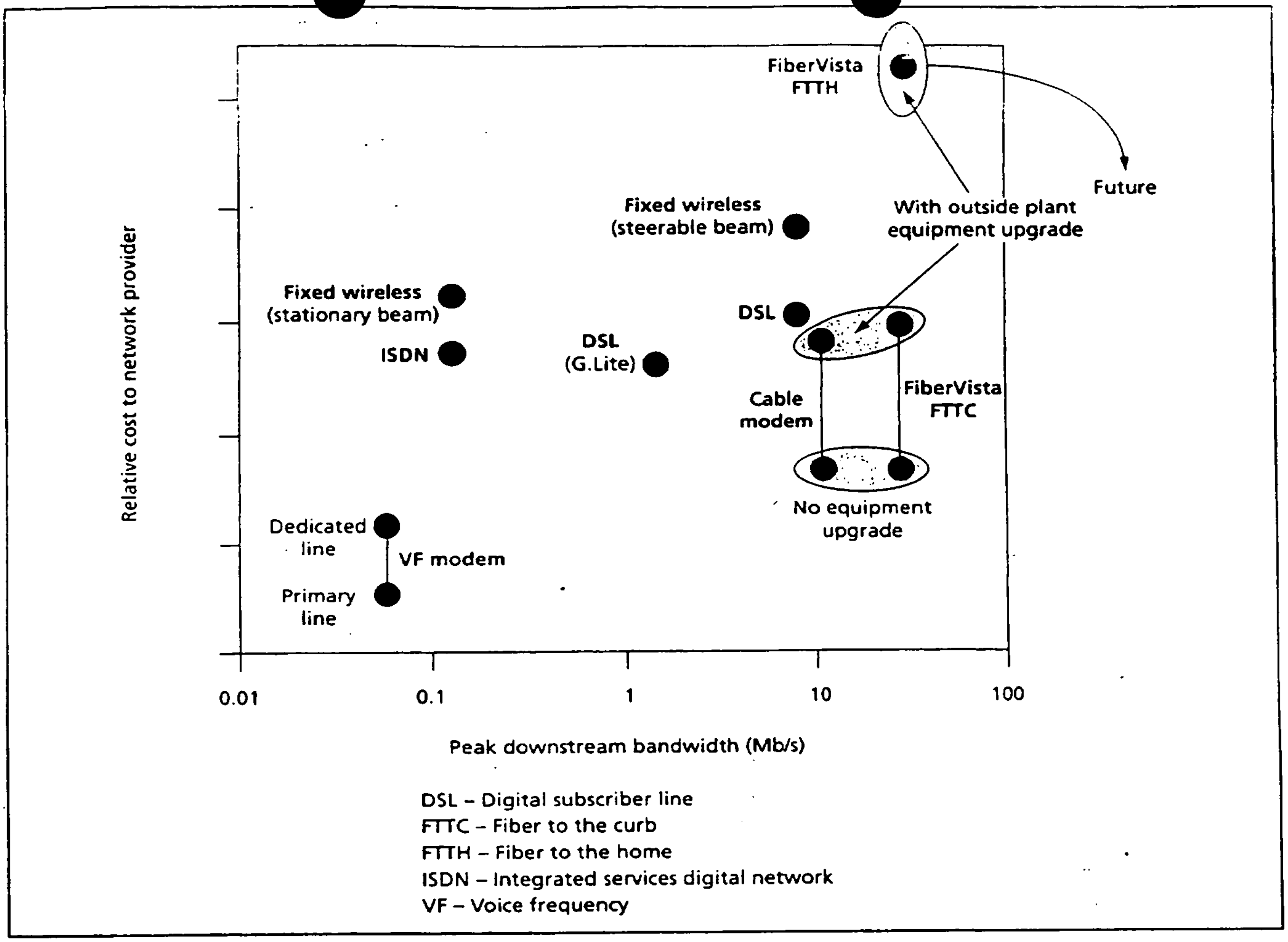


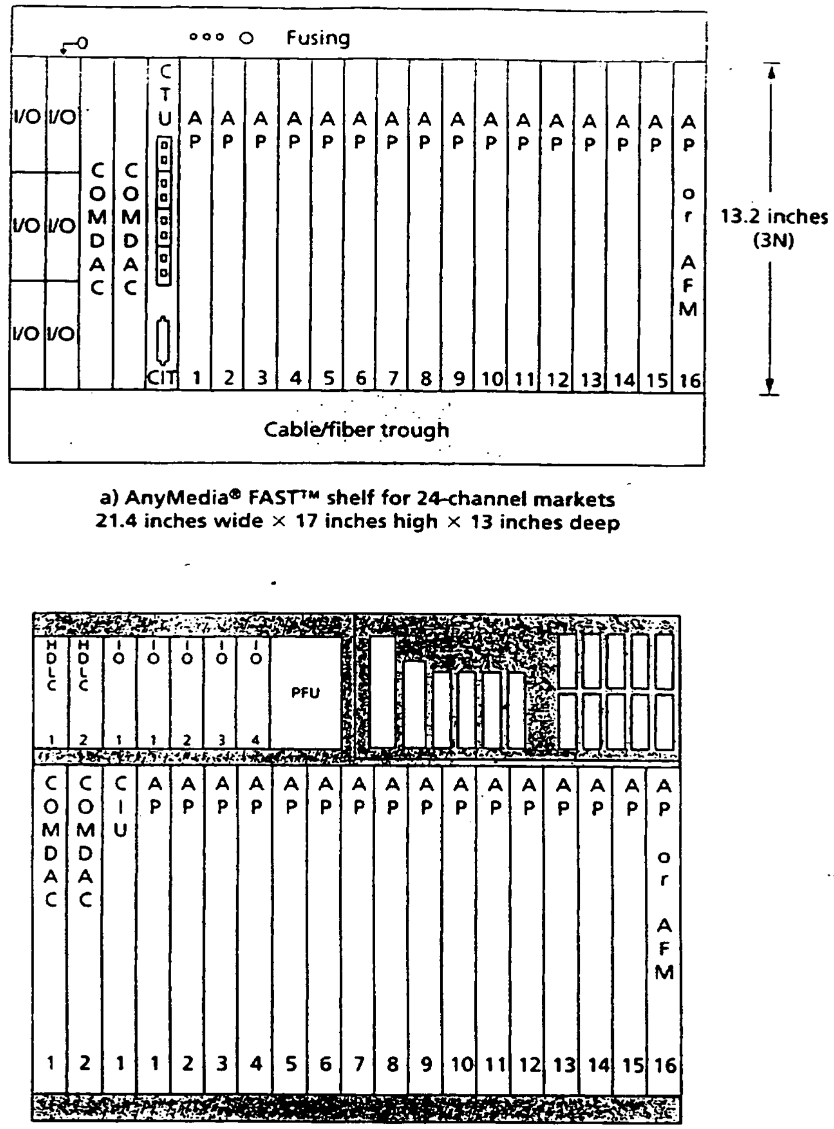
Figure 4.
Comparison of access price versus bandwidth.

(HFC) technology with fiber closer to the home, is priced for two variations: FiberVista FTTC, in which fiber extends to the curb or neighborhood, with passive coax beyond; and FiberVista FTTH, where fiber extends all the way to the end user's home. FiberVista provides enhanced functionality, delivering analog cable TV, digital broadband, and voice services to the subscriber.

Network providers must use this economic data, together with their own input regarding existing assets and infrastructure, to choose the best directions for future investments in technology and networks.

The AnyMedia Access System

Lucent's latest response to the needs of access system customers is the development of the AnyMedia Access System. It is Lucent's first access system that integrates the delivery of narrowband and broadband services in the same shelf, via a common backplane. The earlier HFC-2000 and SDBAS-2000 systems provided common physical transport for narrowband and broadband services, but provided separate equipment shelves for each, implementing two different overlay schemes. The AnyMedia Access System can be configured in an almost infinite number of forms to perform a variety of access equipment roles, even simultaneously in the same shelf. This is accomplished by building on Lucent's AIP, using the AnyMedia AIU and its associated line cards and adapting them to the needs of the open-interface access network. In addition to



a) AnyMedia® FAST™ shelf for 24-channel markets
21.4 inches wide × 17 inches high × 13 inches deep

b) AnyMedia® digital terminal shelf for 30-channel markets

AFM – ATM feeder multiplexer
AP – Application pack
ATM – Asynchronous transfer mode
CIT – Craft interface terminal
CIU – Communications interface unit
COMDAC – Common data and control
CTU – Craft/test unit
HDLC – High-level data link control
I/O – Input/output
PFU – Power filter unit
POTS – "Plain old telephone service"

Figure 5.
AnyMedia® Access System shelf configurations.

providing flexible functional configurations, the AnyMedia Access System has adapted to the differing standards of the 24-channel and 30-channel markets.

The AnyMedia Shelf

The core element of the AnyMedia Access System is the hardware shelf (**Figure 5**), which for the 24-channel

version is the Flexible Access System Terminal, or FAST™ shelf (Figure 5a). The FAST component consists of a hardware shelf for nineteen 3N-size, one-inch-wide, circuit packs and six 1N-size slots. The latter are stacked into the space of two 3N slots, in the 21-slot wide format. The 30-channel version (Figure 5b) keeps the nineteen 3N-size slots in a nineteen-inch-wide shelf, positioning the 1N packs above, in an extended-height shelf format. The transmission and control fabrics are the same for both versions of the AnyMedia shelf, allowing extensive reuse of assets.

The AnyMedia shelf organization follows the major functions it supports. Sixteen 3N-size slots are provided for APs that serve the distribution interface functions. Each AP slot has point-to-point transmission and control connectivity to two common slots dedicated to narrowband switching, shelf control, and network interface functions. Each 3N-size slot connects to two broadband buses (BB bus 0 and BB bus 1) that are used for all cell-based transmission and control functions. For systems providing data services, one or more of these slots must be equipped with an AFM pack. In the 24-channel version, five 1N-size input/output (I/O) slots are provided for PSTN network interfaces with a sixth I/O slot provided for a protection unit. The 30-channel version has seven 1N-size slots, 4+1 for I/O and two slots for high-level data link control (HDLC) processor packs. The AnyMedia shelf transmission fabric is illustrated in **Figure 6**.

An AnyMedia Access System can be partitioned into three elements:

- The *shelf* and backplane, providing the infrastructure;
- The *narrowband subsystem,* serving all access functions for connecting to the traditional time-division-multiplexing (TDM) service network; and
- The *broadband subsystem,* performing the data access functions.

The Bandwidth Pipes—Backplane Transmission Paths

PCM highways are point-to-point transmission paths that connect each AP slot to the COMDAC slots. They transport pulse-code modulated (PCM) data using a TDM format for voice-grade circuits. Two PCM highways are implemented between each AP slot and each of the two COMDAC slots. PCM highways are used also for transmission between the I/O packs and the COMDAC pack, with four PCM highways linking each I/O pack to each COMDAC pack, as in **Figure 7**.

As mentioned above, BB bus 0 is an ATM cell bus that connects to each 3N-size slot in the shelf. BB bus 1 has the same fabric but is not used at this time. ATM traffic passes through BB bus 0 in both directions of transmission; thus, if a service requires 1.5 Mb/s of bandwidth in each direction, it will use 3 Mb/s of cell-bus bandwidth. Although all packs connecting to BB bus 0 can send and receive traffic, for practical considerations one pack must act as the *bus master* and must control access to the bus.

The transmission fabric is complemented by a parallel *control fabric,* consisting of point-to-point universal asynchronous receiver-transmitter (UART) connections between each AP slot and the COMDAC slots, and a fault-isolation bus connecting to all 3N slots. The bus-master pack has control of the fault-isolation bus as well.

The Narrowband Subsystem

The narrowband subsystem performs the DLC functions that are required for interfacing TDM circuit switches and other TDM service nodes via open interfaces. The interfaces supported are

- For the 24-channel markets:
  - TR-08 Mode 1 and GR-303 for switched services, and
  - Integrated network access (INA) for non-switched and non-locally switched services; and
- For the 30-channel markets, V5.1 and V5.2 for both switched and non-switched services.

The physical feeder interfaces are implemented on quad I/O packs (IO_DS1 for 24-channel or IO_E1 for 30-channel systems), as shown in Figure 7. These terminate the transmission facility format in a framer function and map each DS1 or E1 payload of DS0 signals to a PCM highway connecting to a common switch pack. The AnyMedia shelf can be configured to have 480 DS0 feeder channels. This requires five IO_DS1 packs or four IO_E1 packs. The I/O packs can be protected by an optional I/O pack installed in the 1N-size protection slot. This can be switched to functionally replace one failed I/O pack.

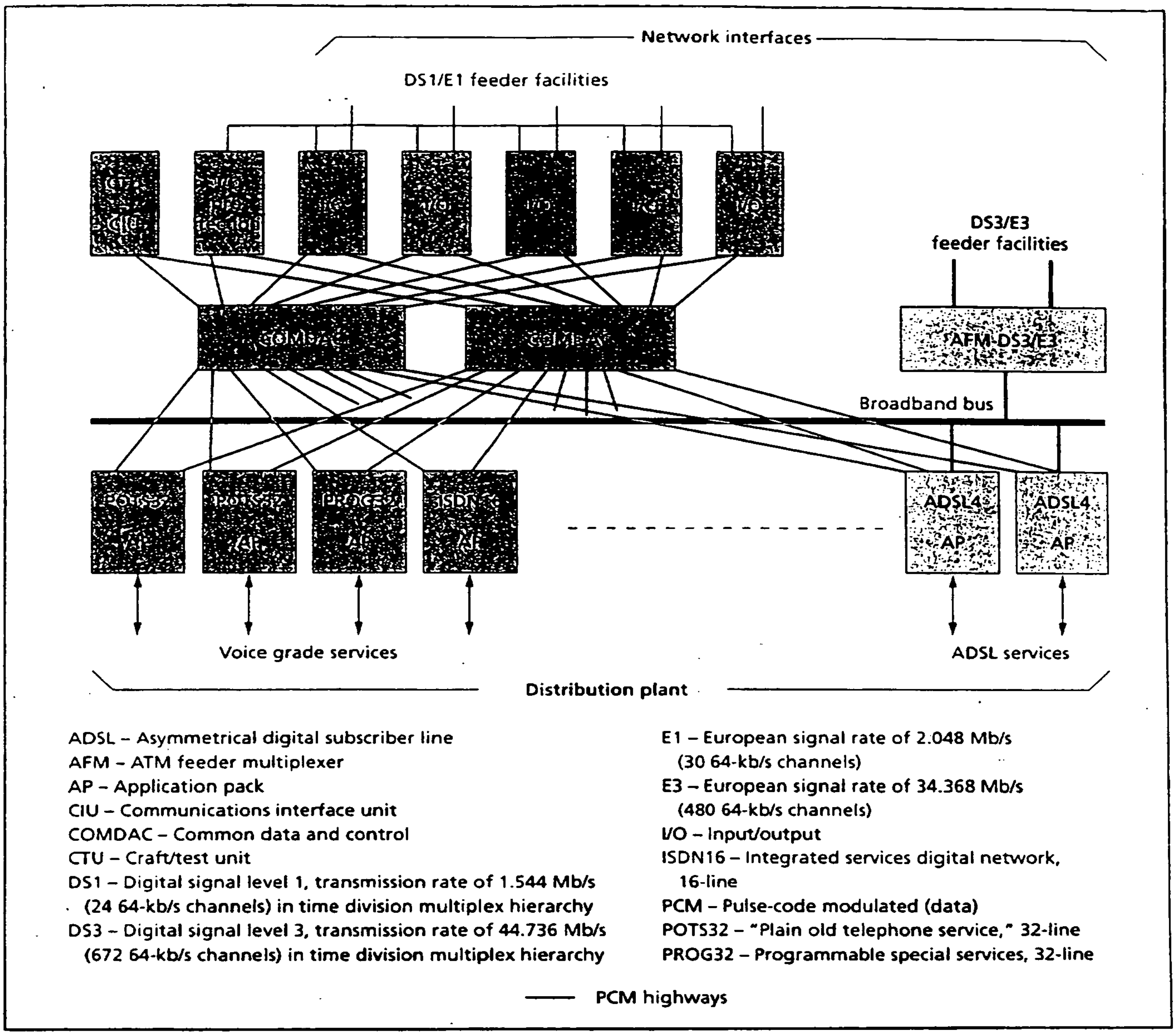
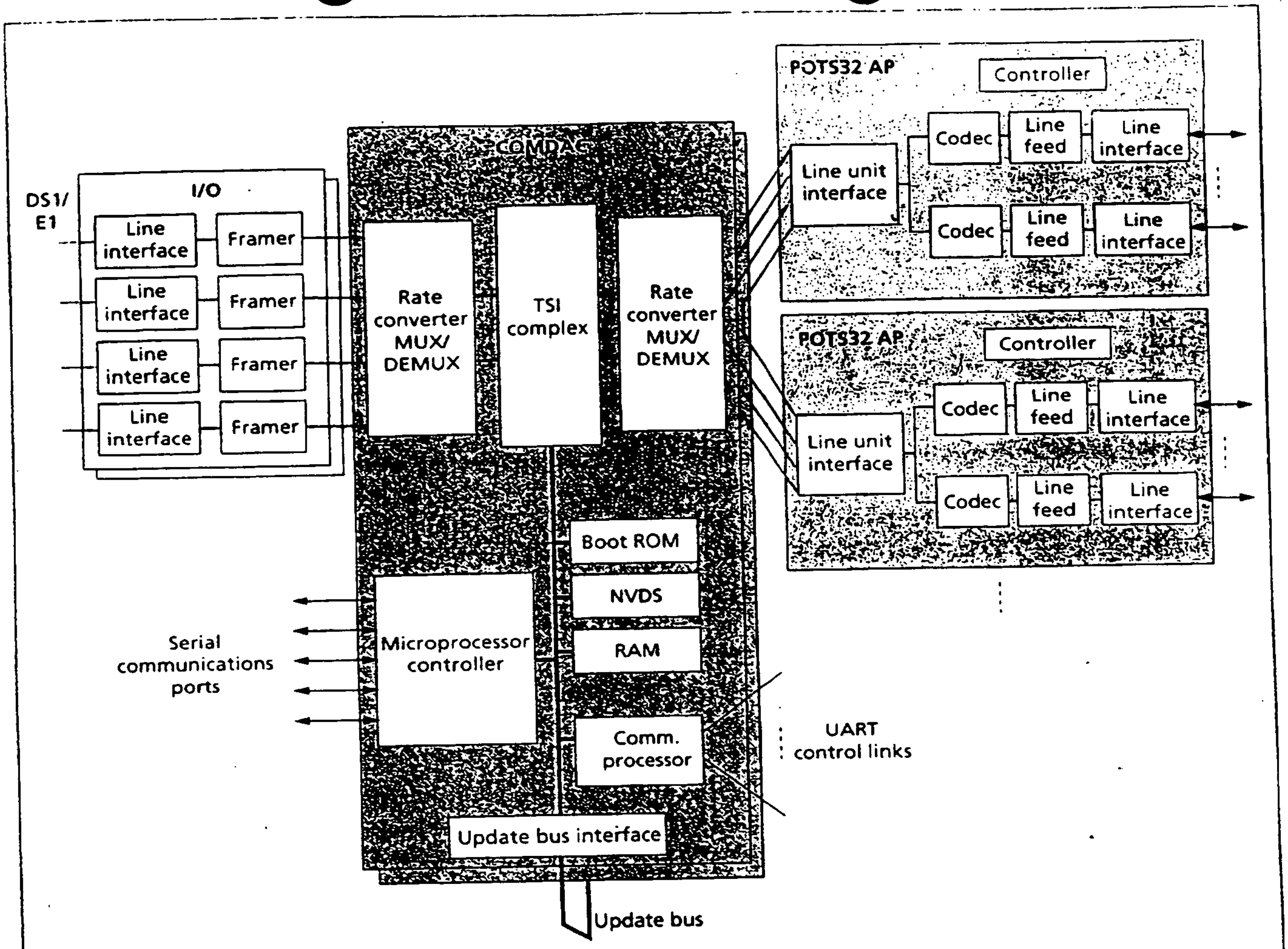


Figure 6.
AnyMedia® Access System transmission architecture.

The COMDAC pack. This pack is the central control-and-transmission element for the narrowband subsystem, and it is the core of the AnyMedia Access System's DLC functionality. The COMDAC pack has four major functional components:

- *Service network transmission and logical interface.* The COMDAC pack terminates the feeder and control links from the switch(es) serving the AnyMedia Access System and executes functions required by the interface standards.
- *Circuit switch.* Using a DS0 time-slot interchanger (TSI), the COMDAC pack provides TDM cross-connecting functions—either dynamically, in response to per-call commands received from a switch, or as provisioned.
- *OAM&P interfaces.* The COMDAC pack handles



AP – Application pack
Codec – Coder-decoder
COMDAC – Common data and control
DEMUX – Demultiplexer
DS1 – Digital signal level 1, transmission rate of 1.544 Mb/s (24 64-kb/s channels) in time division multiplex hierarchy
E1 – European signal rate of 2.048 Mb/s (30 64-kb/s channels)
I/O – Input/output
MUX – Multiplexer
NVDS – Non-volatile data storage
PCM – Pulse-code modulated (data)
POTS32 – "Plain old telephone service," 32-line
RAM – Random access memory
ROM – Read-only memory
TSI – Time slot interchanger
UART – Universal asynchronous receiver-transmitter
—— 4.096 Mb/s PCM highways

Figure 7.
AnyMedia• Access System narrowband transmission architecture.

all narrowband operations, administration, maintenance, and provisioning functions for the AnyMedia Access System.

- *Shelf controller and integrity monitor.* The COMDAC microprocessor controller sends control and provisioning commands to all subtending packs and monitors the health of the transmission and control links to each pack.

The *transmission* functionality of the 24-channel COMDAC pack supports twenty-four PCM highway

interfaces toward the network (feeder) side, twenty connecting to the normally active I/O packs and four to the protection pack. For 30-channel systems, sixteen PCM highways are used for IO_E1 connections and four are used to connect to two HDLC packs. On the distribution side, today's COMDAC packs support twenty-five PCM highways, sixteen dedicated to each of sixteen AP slots, eight shared between pairs of AP slots, and one connecting to the common CTU/CIU slot (see *auxiliary pack* below). The AnyMedia shelf can currently serve a maximum of 768 voice-grade subscriber channels, an average of 48 from each of 16 APs. It will be possible to increase this number in the future.

The *switching* functions of the COMDAC pack are implemented using a TSI device in each direction of transmission. This device cross connects the 768 64-kb/s PCM highway channels on the distribution side to 480 channels on the feeder side. Additional connections are provided to the CTU/CIU auxiliary slot and one to the COMDAC pack's control-and-communications complex. The latter supports embedded control channels for the switch interfaces and optional remote operations channels (ROCs). The TSI fabric also supports the rearrangement of ISDN D channels, which are packed four D channels to a byte for transport over the GR-303 interface.

The *service network interface* function terminates the communications channels between the LDS and the access node, as required by a particular interface standard. The following communication channels are supported:

- For a GR-303 interface,
  - *Time slot management channel (TMC)*, used for connection setup and call processing messages, and
  - *Embedded operations channel (EOC)*, used for maintenance and service provisioning messages.
- For V5 interfaces, physical *communications channels (CCs)* are used to provide transport for logical communications paths (C-paths) for a variety of information types, including bearer channel control (connection setup), PSTN signaling, protection control, and ISDN D-, p-, and f-type data.[3,4] The number of physical CCs is provisionable to suit the number and type of services supported.

Each embedded communications channel (TMC, EOC, or V5 CC) represents a 64-kb/s connection between the host switch and the COMDAC pack, terminating on a serial communications port of the COMDAC pack's processor complex. All communications on these channels are message based; the COMDAC pack processes, executes, and responds to these messages.

The switch interfaces are organized into *virtual remote terminals (VRTs)*, one or more logical access nodes within the physical AnyMedia Access System. The current AnyMedia Access System can support two GR-303 VRTs, up to twenty TR-08 or INA VRTs, or a combination of these. A VRT consists of a set of subscribers and a set of network interfaces with its own complement of embedded communications channels, if applicable. The selection of interfaces in a VRT is made by provisioning: a single GR-303 VRT can serve all 768 telephony subscribers possible on a system; TR-08 VRTs can serve a maximum of 96 lines; and each INA DS1 feeder represents an INA VRT serving 24 channels. Similar functionality exists in V5 systems that connect via E1 interfaces.

The *OAM&P interfaces* are implemented via operations interface channels connecting to the COMDAC pack, either via a dedicated DS0 channel (ROC) or via backplane serial links to the CTU/CIU auxiliary pack. The COMDAC pack supports interfaces to a 10baseT Ethernet LAN, a local RS-232 operations link, a local RS-232 craft interface terminal (CIT), and a local RS-232 interface to an external test unit.

The COMDAC microprocessor contains a RISC processor core that is supported by a programmable logic device (PLD) containing a watchdog timer and reset logic. The processor complex is augmented with a digital-signal-processor (DSP)–based *communications processor* that interfaces to twenty-four UART control links, one for every circuit pack in the shelf. These control links serve as control-and-communications links between the COMDAC processor and the on-board processor in each AP or I/O pack.

The COMDAC pack uses an *update bus* to maintain memory synchronization with a standby COMDAC

pack. This provides 1+1 protection, where required. With both packs installed, all memory write cycles by the active COMDAC pack result in an identical write cycle in the standby pack's memory. When a COMDAC switch occurs and the standby pack "wakes up," its memory image is the same as that of the formerly active pack, which it then replaces. A side switch can occur in response to a fault in the active COMDAC pack, or in response to a maintenance command.

The COMDAC pack is augmented by an *auxiliary pack* that collects hardware-intensive, non-service-affecting functions—such as the physical layer interface functions required for the operations interfaces with local ports and the circuits required to perform subscriber channel and line testing. (As noted above, the local ports are 10baseT LAN and RS-232 ports for the CIT, remote operations, and remote test unit control interfaces.) The auxiliary pack is called the *craft/test unit (CTU)* in the 24-channel version of the AnyMedia Access System and the *communications interface unit (CIU)* in the 30-channel version, with minor market-dependent differences between the two.

The COMDAC pack's processing capacity is also augmented in the 30-channel markets by one or two *HDLC packs* if ISDN services need to be supported. The HDLC pack multiplexes ISDN D channels into a smaller number of V5 CCs. A second HDLC pack is optional for protection.

Narrowband application packs. Telephony APs make the narrowband subsystem complete. The AnyMedia Access System currently supports a range of telephony APs that can serve POTS, two-wire special services, coin, and ISDN basic-rate-interface (BRI) subscriber services. These packs are AIP assets and can be reused in compatible applications. Many share identical functions, but differ due to the services supported and due to regional standards. The telephony APs interface with the AnyMedia Access System backplane via the PCM highways for the transmission and control links.

A unique AnyMedia Access System feature provides a link to the past—an adjunct shelf that can support up to twenty-four SLC Series 5 or SLC-2000 channel units (line cards). A server AP installed on the AnyMedia shelf extends the backplane signals to the *metallic distribution shelf 2 (MDS-2)* which re-creates the SLC backplane to support channel units from earlier systems. Over the years, Lucent has accumulated an extensive library of special-services line cards for its access products. Some special services are rare and customer specific. Via the MDS-2, the customers can provide these services via packs that they may already have in inventory, or via packs available from Lucent's older product lines.

The Broadband Subsystem

The AnyMedia Access System's broadband subsystem is an ATM access concentrator that interfaces the ATM service network with digital subscriber lines. The service network interface that is currently supported conforms with the ATM Forum's user-network interface (UNI 3.1) specification[6] and the ITU-T I.432 recommendations,[7-11] to be upgraded to UNI Version 4.0 in a later release. In its role as a concentrator and host for remote line terminations in the access network, the AnyMedia broadband subsystem parallels the functionality of a DLC system in the TDM network, but for the packet-switched ATM network.

The AnyMedia shelf BB bus serves as the system's routing fabric. Cell headers are used in directing ATM traffic between a feeder port on an AFM pack in one AP slot and the subscriber ports on the ADSL APs in other slots. The broadband subsystem consists of these two circuit pack types. Data-only configurations may utilize an AFM pack in slot 16 and up to fifteen ADSL packs. Only ATM ADSL services are supported on the broadband APs that are currently available. With the appropriate adaptation layer functions, future APs will support the transport of IP traffic entering via Ethernet or frame-relay ports.

ATM feeder multiplexer. The AFM circuit pack is the core of the AnyMedia broadband subsystem (**Figure 8**). It incorporates the physical and logical service network interfaces, an ATM core fabric, the BB bus master control functions, and the control functions required to provision and operate all subtending broadband packs in the system. The current AFM pack has two DS-3 or two E3 ports, one connecting to the service network and one optionally connecting to an AFM in another shelf in a daisy-chained feeder configuration. The AFM provides an ATM Forum UNI inter-

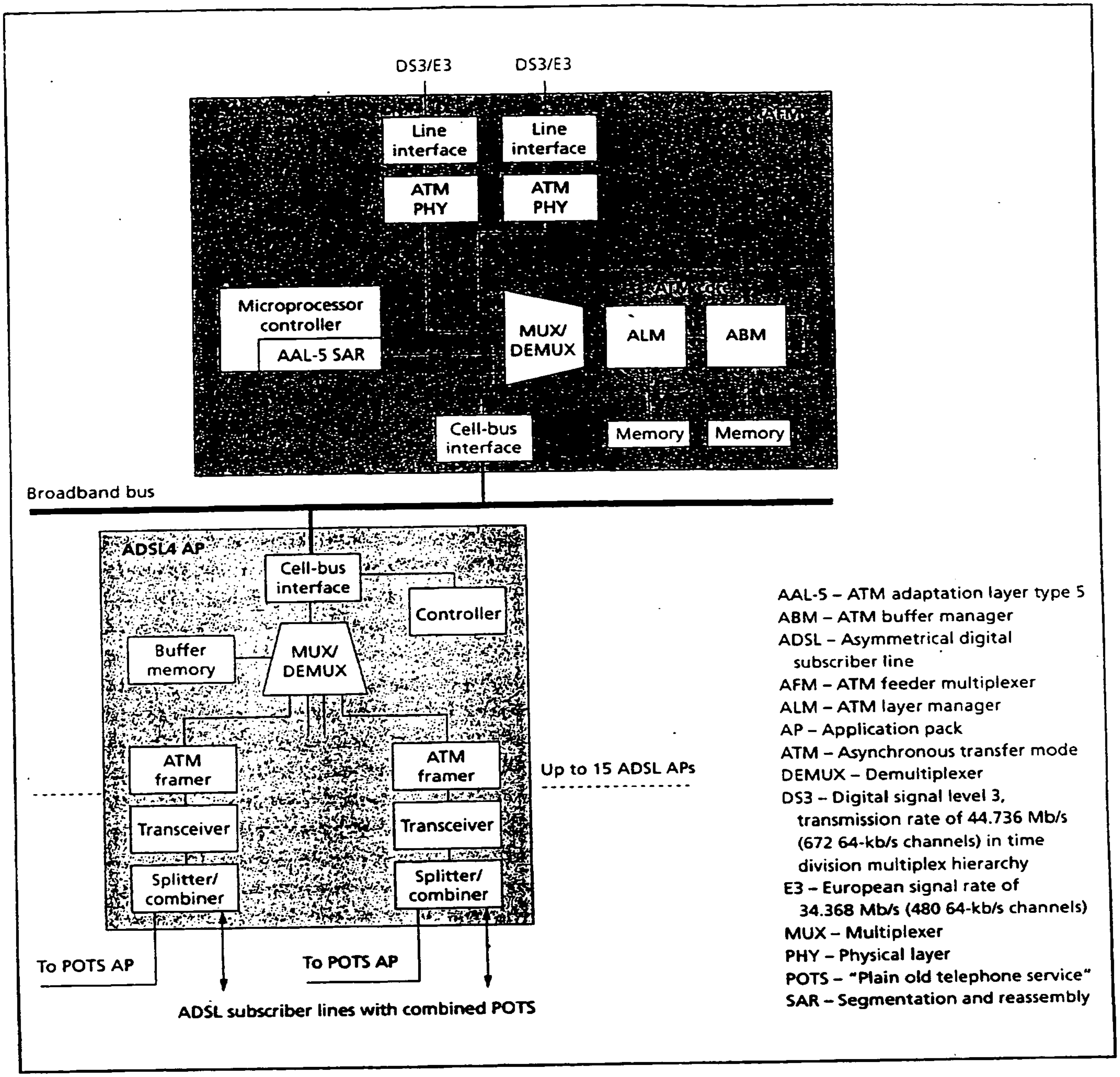


Figure 8.
AnyMedia• Access System broadband transmission architecture.

face toward the service network for which it includes the physical layer elements. The AFM connects to the network via faceplate coax connectors; OC-3/STM-1 and DS1/E1 inverse-multiplexing versions of the AFM are under development.

The AFM's ATM core uses the Lucent Microelectronics ATLANTA™ chip set as the cell-processing engine and contains an ATM cell multiplexer/demultiplexer block. The MUX/DEMUX block connects several components to the ATM core, including two DS3/E3 ATM physical-layer devices, a cell-bus interface device, and the AFM processor core's Type 5 ATM

adaptation layer (AAL-5) segmentation-and-reassembly (SAR) function port. Besides the MUX/DEMUX block, the ATM core consists of an ATM layer manager, which supports all ATM layer functions, and an ATM buffer manager (ABM), which manages upstream cell buffering from each subscriber port according to the QoS parameters set.

The AFM's controller uses a device that has an integrated AAL-5 SAR function, which is used to terminate all control connections between the AFM and its ATM environment.

The AFM's backplane interface uses the same cell-bus interface device as all packs connecting to the BB bus; however, in the AFM the interface can be configured to be the bus *master*, with the *slave* mode being available for configurations using multiple AFMs in the same shelf. In addition to the cell-bus interface, the AFM provides the following backplane interface functions:

- Sourcing of BB bus clock signals,
- Application of a bus-termination bias voltage, and
- Control of a fault-isolation bus, used for low-level communications between the AFM and other packs connecting to the BB bus.

The *AFM operations interfaces* include ATM permanent virtual circuits (PVCs) terminating on the processor's SAR function. Planned uses are for simple-network-management-protocol (SNMP) links—used for provisioning, alarms, and performance monitoring—and file-transfer protocol (FTP) links—for software download and configuration-data backup or restore operations. The AFM can also process special ATM cells to provide ATM layer maintenance and performance monitoring for virtual path and virtual channel connections. Additionally, physical operations interfaces for LAN or local craft access are provided on the AFM in the form of a 10baseT Ethernet interface and an RS-232 interface provided on the AFM faceplate.

The ADSL4 applications pack. The other element of the initial AnyMedia broadband subsystem is a line card with ADSL line terminations (Figure 8). The ADSL4 AP supports four full-rate, rate-adaptive, ADSL line terminations with an ATM transmission layer. The ADSL4 uses a discrete multi-tone-technology ADSL transceiver chip set that is compliant with ANSI T1.413, Issue 2.[12] The downstream transmission rates that are now supported range from 32 kb/s to 8.912 Mb/s. Upstream rates range from 32 kb/s to 640 kb/s. An adaptation procedure is performed as part of the start-up sequence of each ADSL line to guarantee a grade of service with the available line conditions. The pack can also support the ITU-T G.Lite service category (maximum 1.5 Mb/s downstream).

The ADSL4 pack includes an on-board "POTS splitter." This is a set of passive filters facilitating the combination of voice and ADSL services on a single subscriber loop. The voice lines are connected to the ADSL4 pack from a standard voice-grade line card, such as the AnyMedia POTS32 AP, via the ADSL4 faceplate. The subscriber loop connections on the ADSL4 have both services on the same twisted pair. The use of a similar filter on the subscriber end is anticipated. To ease the implementation of a POTS-ADSL interconnect, Lucent has developed a special protector/jumper cable component that replaces the standard line-protection device in the main distribution frame and connects the POTS pack wire pair and the subscriber drop wire pair to the ADSL4 pack.

The ADSL4 pack interfaces to the BB bus via the standard AnyMedia cell-bus interface device. The bus interface connects to the common port of a 4:1 cell MUX/DEMUX device that connects to four ATM framers, each one serving one ADSL port. The ATM cell MUX is supported by a random-access-memory (RAM) buffer for downstream cell buffering.

ATM cell flow. The AnyMedia Access System provides transmission of ATM cells between the AFM feeder interfaces and ADSL subscriber ports installed in the system. Provisioned ATM PVCs are supported now, with switched virtual circuits (SVCs) to be added later. The initial release supports unspecified-bit-rate (UBR) services only, with non-real-time variable-bit-rate (nrt-VBR), real-time variable-bit-rate (rt-VBR), and constant-bit-rate (CBR) service categories being features of the next release.

In addition to end-user traffic, virtual channels (VCs) are supported for control purposes between the switch (or service network) OAM&P system and the

AFM. The AnyMedia Access System also supports both remote provisioning of each subscriber terminal served (via integrated local management interface [ILMI][13]) and VCs between the AFM and the controllers of each AP accessing the BB bus. The latter require AAL-5 functions for each controller. These permanent connections are used for control and provisioning, and are established at the time of the installation of each unit.

ATM cross-connections are virtual connections between channels transported over the AFM's feeder port(s) and subscriber ports. They can be either *virtual path connections (VPCs)* or *virtual channel connections (VCCs)*. The connections are executed via virtual path identifier (VPI) and virtual channel identifier (VCI) address translations between the VPI/VCI values used at the feeder UNI interface and those used on the subscriber UNI interface, followed by routing the subject cells along the path designated by the addresses. VPCs can take any valid VPI value out of the 255 available on a UNI interface. In the case of multiple daisy-chained systems connecting via a single UNI, the 255 VPIs are shared across all shelves of the chain.

At the time a new circuit or path is set up, the AFM provisions VPI/VCI translation tables for itself and for the cell-bus interface devices on other packs. Address translations take place in the cell-bus interface devices prior to a cell's egress onto the BB bus. The AFM also provisions the routing tables for the MUX/DEMUX devices on the APs. The translation tables and the routing tables define a cell's path through the system.

ATM cell buffering. ATM cell buffering is required in each direction of transmission. Cell buffering allows the ATM cell streams to be rate-paced to the current egress rate of a given physical port—that is, the varying ingress rates and internal transmission rates are matched to that of the egress port. In the AnyMedia Access System, *downstream cell buffering* is provided on the ADSL AP and is situated between the cell-bus interface and the ADSL ports. The ADSL4 AP supports only UBR traffic; later packs will support CBR, rt-VBR, and nrt-VBR traffic categories in addition.

Upstream buffering is provided on the AFM pack in the form of a common cell buffer serving all circuits. It is controlled by the Lucent Microelectronics ABM device. This buffering is used primarily to facilitate rate pacing of the upstream traffic that has been aggregated by the AFM to the DS3 or E3 port rate. The buffer is managed separately for each of the four transmission ports connecting to the AFM's ATM core services: the cell-bus interface, two DS3/E3 ports, and the AFM processor's integrated SAR port (see Figure 8).

Service quality control. The AnyMedia Access System's broadband subsystem provides three mechanisms to guarantee the QoS it provides:

- Connection admission control (CAC),
- Usage parameter control (policing), and
- Upstream congestion management.

CAC is a set of procedures performed by the AnyMedia broadband subsystem to determine whether a new connection can be established with the requested QoS parameters, taking into account the connections that already exist in the system. If a connection is accepted, the AFM generates the necessary configuration instructions for the devices on the AFM and the AP that are required to implement the connection routing, and it provisions the cell-bus interfaces and the cell MUX/DEMUX devices. The first AnyMedia broadband subsystem release provides a minimal connection-admission process in the form of a provisioned overbooking factor that is suitable for UBR services. A later data release will support the CAC procedures outlined in the ATM Forum's Traffic Management 4.0 specifications.[14]

Usage parameter control, or policing, services by the AnyMedia broadband subsystem ensure that the upstream cell traffic does not violate the connection's traffic contract descriptors. Cells in excess of the parameters established by the CAC will have their cell-loss priority (CLP) bit set via a leaky-bucket algorithm. Cells with CLP=1 are discarded if the AFM detects congestion on the feeder interface. The first release of the AnyMedia broadband subsystem can police the peak-cell-rate parameter of UBR services, if so provisioned. The next release implements usage-parameter control procedures required by the ATM Forum's Transmission Management 4.0 Specification for the service classes supported.

Upstream congestion management guarantees that the traffic fed to the AFM feeder ports does not exceed the

feeder facility capacity, discarding excess cells intelligently when congestion occurs. Congestion is indicated by near-overflow of the AFM's cell buffer. Cells with CLP=1 will be discarded first, followed by cells of the lowest priority. To improve network performance, the AnyMedia broadband subsystem will provide the option to discard all cells remaining in an AAL-5 protocol data unit—that is, a string of cells representing a data unit such as an IP packet. The entire protocol data unit will have to be re-transmitted, so transmitting the remaining unusable cells just adds to the congestion.

Managing the AnyMedia Access System

The AnyMedia Access System supports a rich set of interfaces that are intended for the OAM&P functions required to manage the system or the access network it serves. The AnyMedia system has the usual indicators for craft that identify failed packs or external interfaces. CIT interfaces that can be used for all provisioning and maintenance functions are provided. Although all such functions can be performed via low-level TL1[15] messages exchanged via the CIT, Lucent also provides a graphical system interface (GSI) on a laptop-PC platform. The GSI permits intuitive, point-and-click craft actions to determine system parameters (status, configuration, and inventory), to change component status (in-service/out-of-service), and to provision system elements. The GSI/CIT interface can be used to download new software to all packs supporting this feature. The GSI/CIT functionality is available remotely as well, via a variety of communications channels and protocols.

Element management functionality for the AnyMedia Access System is provided via two subsystems, one for telephony and one for broadband access. The element manager provides an efficient way of managing multiple AnyMedia systems, providing a central base for administration and provisioning of system configurations, maintenance actions, and hardware/software version control. The element manager can be connected either locally or via the system operator's data communications network to serve a larger number of systems.

The AnyMedia Access System can also interface to legacy operations-support systems operated by local exchange carriers (LECs) to manage their telephony networks. Examples are Telcordia Technologies' OPS/INE[16] for provisioning, telecommunications management network (TMN)[17] and Telcordia's NMA* system[16] (network monitoring and analysis system) for fault management, and Lucent's Mechanized Loop Testing System for loop testing. Mechanized Loop Testing is currently being updated to support testing of combined POTS and ADSL lines.

AnyMedia Access System Software Overview

The AnyMedia Access System employs two primary processors—the COMDAC pack, which is responsible for narrowband operations, and the AFM, which is responsible for broadband operations. In order that the AnyMedia system be deployable in narrowband-only or broadband-only configurations, the narrowband software and broadband software can operate nearly independently of one another.

While AnyMedia system peripheral packs are intelligent, their functionality is limited to low-level control of the peripheral hardware at the direction of the COMDAC pack or AFM. As such, the software/firmware associated with these packs will not be described here.

The narrowband and broadband software and software architectures are based on object-oriented design principles. They are implemented in C++ with the ObjecTime Developer* visual-design and code-generation tool using real-time object-oriented modeling (ROOM) methodology. The ChorusOS* operating system is used.

Narrowband Software

The software on the COMDAC pack is responsible for all functionality associated with the narrowband portion of the AnyMedia system, including call processing and OAM&P. In order to facilitate use of the software in both the 24-channel and 30-channel products (which require different call-processing and OAM&P functionality), a platform approach using two software planes is taken (**Figure 9**).

Software that is common to the AnyMedia system generically is included in the *platform plane*, while software specific to the 24-channel and 30-channel markets is included in their respective product planes. The platform plane is a separately compilable and testable entity that is configured both

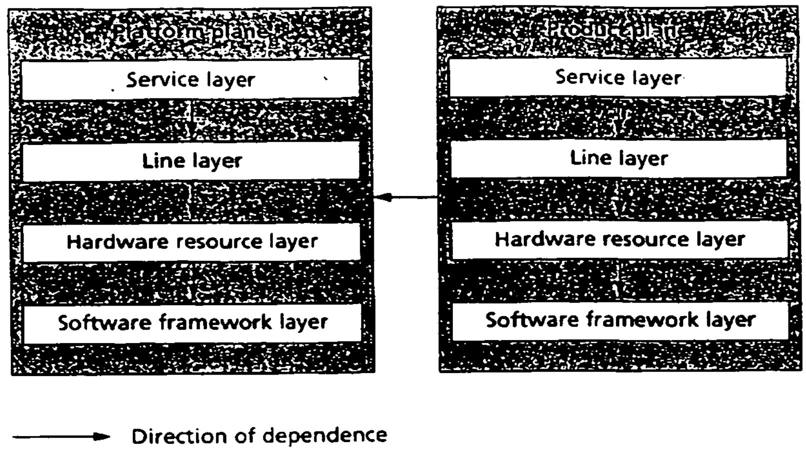


Figure 9.
Dual-plane narrowband software architecture and software layering.

at compile time (via product-plane configuration files) and at run time (via specific requests from product-plane software). The product planes are built upon the platform plane to create a 24-channel or 30-channel specific software load.

Within each plane, the software is divided into four layers: the *software framework layer*, the *hardware resource layer*, the *line layer*, and the *service layer*. Software entities within each layer may be dependent upon entities within the same or lower layers, but not upon higher layers. The highest layer is the service layer, consisting of high-level application code that implements major customer-visible features. This layer tends to be the most product specific. The line layer is next, consisting of software entities that represent logical resources used by service layer software (for example, lines). Next is the hardware resource layer, consisting of abstractions of the physical hardware of the system, including packs and shelves. At the lowest layer is the software framework layer, which provides common services to be used by all software entities. As it implements basic system services, this layer tends to be the least product specific.

Platform plane. The majority of the software in the platform plane resides within the *software framework layer*. Here, the system implements the software necessary to control initialization and side switching. This layer also contains a collection of configurable software that provides the following functionality:

- Management of transmission paths through the TSI fabric of the COMDAC pack, with the ability to connect any feeder-side time slot to any distribution-side time slot under the control of application software;
- Database management of both volatile and non-volatile records (with table formats provided by product plane configuration files);
- Generic management of the equipage states of hardware entities such as shelves and packs (without specific knowledge of the entities themselves);
- Management of faults and alarms by a generic engine, with the specific faults and alarms being specified by product-plane configuration files; and
- Complete decoupling of the external interface front end from the back-end implementation software through use of a generic command router.

At the *hardware resource layer* of the platform plane, the software provides an abstraction of the hardware based on the topology of the system. The software models the system hardware as objects representing a primary shelf (the AnyMedia shelf) and a set of optional subtending satellite shelves (referred to generically as "sub-shelves") that are hosted by server packs

installed in the primary shelf. Except for the AnyMedia shelf object, which is inherent to the system (and so is created unconditionally at system initialization), the shelf objects are created and destroyed dynamically as shelves are added to or removed from the system via provisioning. Within the shelf representation, objects that represent packs plugged into the shelf are created when the software detects the presence of a pack, and they are destroyed when the pack is removed from the shelf. Hardware resources provided by packs (such as customer line interfaces, or "drops") are themselves modeled as objects contained within the pack objects. The association of a sub-shelf with a server pack on the AnyMedia shelf is modeled as a cross connection of the "server port" from a particular server to the sub-shelf. At present, the only major narrowband hardware entity that is common among multiple products is the COMDAC pack. As such, it is the only complete hardware abstraction provided within the platform plane. However, the platform plane provides a number of base classes from which all product-plane shelf, pack, and hardware-resource objects are derived, ensuring a consistent model among all products that are built upon the platform.

As there are no common line-layer entities in the system, the platform plane line layer is currently empty.

The platform plane contains *service layer* software that implements user-interface functionality common to all AnyMedia products. Such functionality includes a generic TL1 engine—with the specifics of the TL1 sessions being supplied by product-plane configuration files and run-time requests—as well as support for transmission-control-protocol/Internet-protocol (TCP/IP) and serial OAM&P interfaces. This layer also contains software to support Telnet, FTP, and point-to-point protocol (PPP). Finally, software responsible for the installation of new software loads resides in the service layer.

Product plane. The *software framework layer* of the product plane consists exclusively of configuration files that customize the platform to the needs of the product. These needs include the specification of product-specific database tables, alarm information, and identifications for all entities in the system (known as AccessIDs).

The *hardware resource layer* of the product plane consists of the product-specific shelf, pack, and hardware resource objects that are derived from the base classes provided by the platform plane.

The *line layer* of the 30-channel product plane provides abstractions of the logical line resources that are used by the service-layer application code. The line-layer software permits the flexible association of any logical line with any physical drop in the system. For the 24-channel product, lines exist solely within the context of VRTs (at the service layer), leaving this layer empty.

The *service layer* of the product plane contains software that implements high-level features such as call processing, provisioning, testing, and performance monitoring. For the most part, the software in this layer is associated with particular switch interfaces. For 24-channel markets, abstractions of the switch interface are provided by three different types of VRT objects: GR-303, TR-08 (Mode 1 only), and INA. The 30-channel product is oriented around the V5 standard, providing objects that abstract the V5.1 and V5.2 interfaces. These objects encapsulate a commercial V5.x software package and adapt its application program interface to that of the AnyMedia software. In all cases, the switch interface abstractions allow for the flexible association of lower-layer resources with any switch interface. That is, within the 24-channel system, any physical drop or DS1 feeder can be associated with any VRT. Similarly, the 30-channel software permits any logical line or E1 feeder to be associated with any V5.x interface.

Broadband Software

The software on the AFM is responsible for all functionality associated with the broadband portion of the AnyMedia system, including connection control and OAM&P. Unlike the narrowband portion of the system, there is no distinction between 24-channel and 30-channel markets in the broadband software; hence, no concept of a software platform is required. The minor differences that do exist between the 24-channel and 30-channel applications (such as DS3 versus E3 feeder) are handled by provisioning.

Like the COMDAC pack software, the AFM software is strictly layered, with dependencies allowed

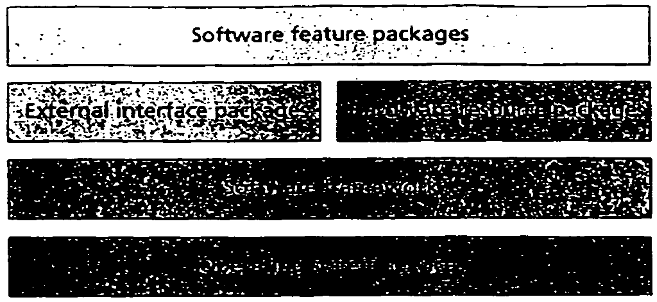


Figure 10.
AFM software layering.

only from upper layers to lower ones. The AFM software is stratified into five layers: *software feature packages, external interface packages, hardware resource packages, software framework,* and *operating system services* as shown in **Figure 10**.

The *software feature packages* layer handles broadband feature-specific applications. Since most of the data-transport features are handled by the AFM hardware, the primary functions of these packages are in support of OAM&P functions, such as:

- Configuration management,
- Connection management,
- Initialization management,
- Alarm and fault management,
- Performance management,
- Traffic management, and
- Security management.

External interface packages serve as links between the AFM software and external entities, which include:

- IP services such as FTP, Telnet, and inetd;
- Local and remote SNMP-based network and element managers;
- The ADSL AP circuit packs on the broadband shelf;
- The COMDAC circuit pack on the shelf; and
- OAM&P cells from the ATM switch.

The *hardware resource packages* are the primary interfaces between the AFM hardware devices and the AFM software. They are structured as "drivers" and are accessible both by ChorusOS tasks (via ChorusOS system calls) and by ObjecTime actors (via ObjecTime transition code access to these same system calls).

The *software framework* packages provide a basic framework of capabilities needed by the AFM software. These packages support the following functionality:

- Initialization sequencing,
- Management of connections between any distribution-side VP/VC port and any VP/VC port on the DS3/E3 interface,
- Database management capable of managing both volatile and non-volatile data,
- Management of the equipage and slot states of the AFM and the broadband APs, and
- A generic engine for management of faults and alarms, including an SNMP alarm/trap handler to connect to the SNMP environment.

The *operating system services* layer consists exclusively of services provided by the ChorusOS operating system.

Operating Systems and Development Environment

The COMDAC and AFM processors run the ObjecTime run time system on top of the ChorusOS operating system (which also provides the TCP/IP stack and IP forwarding capability required by the COMDAC software). The AnyMedia Access System utilizes the Green Hills[18] C++ compiler and their MULTI* debugger.

AnyMedia Access System Architecture—Variations

The AnyMedia Access System and its components, described in the preceding sections, are intended to serve as a platform for applications beyond the traditional DLC or DSLAM configurations inherent in the basic architecture. Opportunities exist in taking advantage of the intellectual, software, and hardware assets available either from the AnyMedia Access System or from the Lucent AIP family of products. We next discuss some of the possible architectural variations, starting from the simple adaptations needed for configuring a host terminal for *integrated access devices*, then discussing the adaptations needed for combining POTS and ADSL services on a single AP. More radical changes to the distribution solutions offered for the access network provide us with a *host digital terminal* for FTTL.

Host Terminal for Integrated Access Devices

One of the configurations depicted in Figure 1 shows an AnyMedia Access System acting as a host terminal for an integrated access device (IAD). IADs have evolved in recent years to provide voice and data (Ethernet) line terminations in small offices via standard trunk connections (DS1/T1 or E1 rate). An IAD, located on a subscriber's premises, serves a limited number of POTS lines (typically from a few to twenty-four, maximum) and a number of data connections via an Ethernet LAN port. The network-side connection is in the form of DS1 or E1 rate services that transport DS0 channels for voice and an $N \times$ DS0 channel for data.

The functions of an AnyMedia Access System serving as an IAD host terminal (**Figure 11**) are:

- To serve as an access device for the voice lines, connecting them via the GR-303 or TR-08 switch interface to the TDM network; and
- To transmit the $N_y \times$ DS0 data channels, connecting multiple (y) IADs, to the data network without alteration. (Note that the number of data DS0s for each IAD, N_y, can be different.)

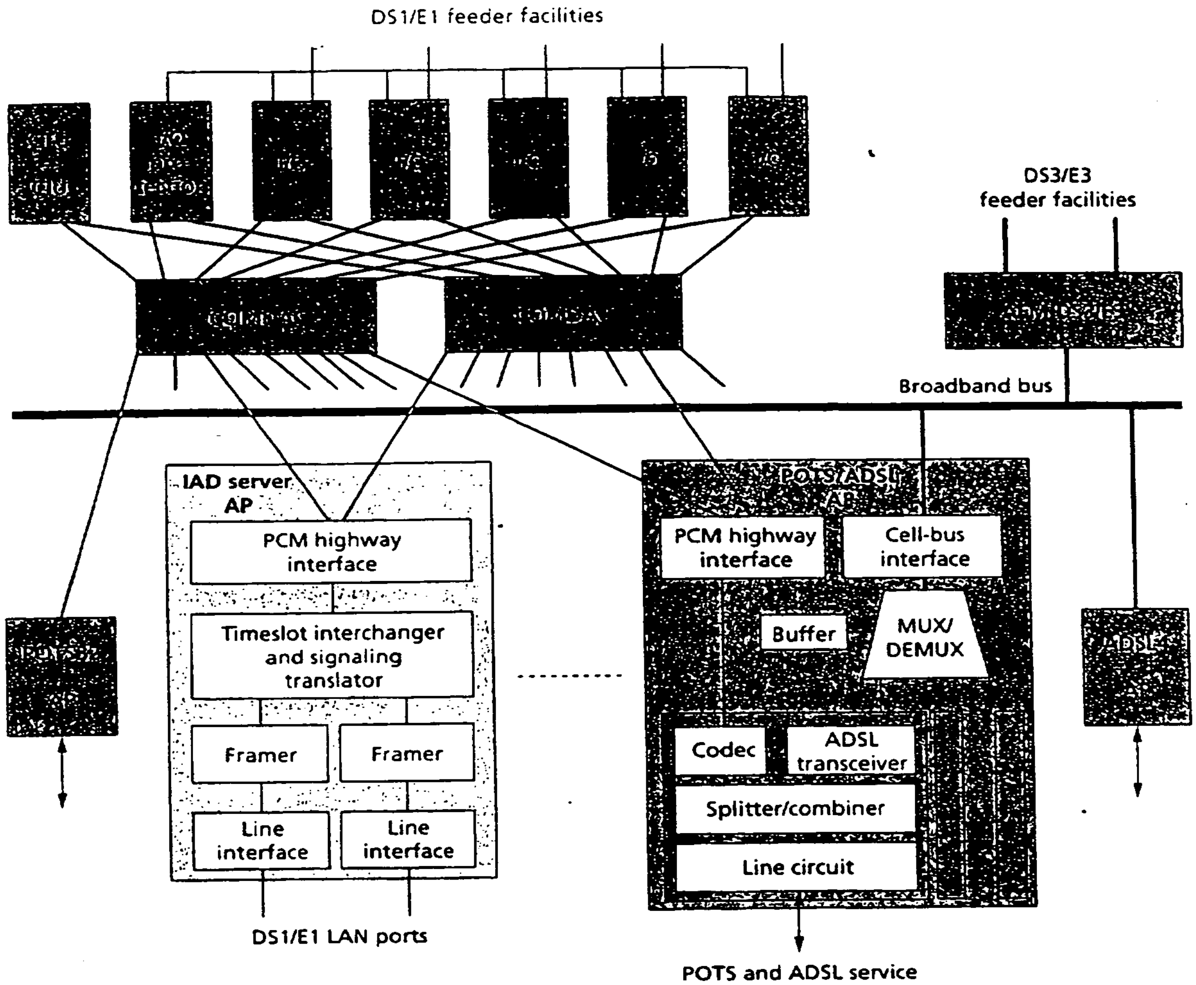
The AnyMedia Access System can perform both voice and data tasks, requiring only a DS1/E1-rate AP (the IAD server pack) as a new asset. The IAD server pack connects up to forty-eight DS0 channels via the two PCM highways that connect to it, and maps them to two DS1/E1-rate ports. The first instance of an IAD server has two DSX-1 format ports. T1 and high bit-rate DSL (HDSL) physical formats are planned for later.

A critical requirement from the AnyMedia host terminal is that the data channels from its IAD server port be connected to the DS1/E1 feeder that serves non-switched channels so that frame integrity is maintained. Such cross connections are supported by the COMDAC pack. In addition to its transmission functions, the IAD server pack can map optional OAM&P data links serving each IAD to the UART control link connecting to the COMDAC. This provides a communications link between each IAD's controller and the AnyMedia system's COMDAC pack. (For DS1-rate links, this may be the extended superframe data link of the DS1. This could become a DS0 in the future.)

Combined POTS and ADSL AP

Perhaps the most obvious opportunity provided by the AnyMedia shelf backplane is the support of simultaneous access to the narrowband and broadband fabrics. Current ADSL technologies have evolved around the concept of providing ADSL data and voice telephony services over the same subscriber loop, eliminating the need to install an additional pair of wires to each ADSL subscriber. The first ADSL offerings, both from Lucent and from its competitors, had the POTS and ADSL line terminations on separate circuit packs, with the signals being combined in a "POTS splitter/combiner" filter. Lucent's ADSL4 pack incorporates such a filter, as was illustrated in Figure 8. Although it is conceptually simple to wire the POTS twisted pair to the ADSL AP, the operations systems used by the LECs were not designed to handle such connections gracefully.

A future POTS/ADSL AP will solve the problem by implementing POTS and "ADSL Lite" line terminations and the splitter/combiner on the same pack (Figure 11), with a single twisted-wire pair to connect to the subscriber loop. ADSL Lite service is defined by the ADSL Forum,[19] Universal ADSL Working Group,[20] and ITU-T[21] G.Lite standards bodies as a low-cost ADSL option for residential and small office applications. It limits the downstream bandwidth to 1.5 Mb/s and can be implemented without the subscriber-end splitter/combiner filter. On its backplane



ADSL – Asymmetrical digital subscriber line
AFM – ATM feeder multiplexer
AP – Application pack
CIU – Communications interface unit
Codec – Coder-decoder
COMDAC – Common data and control
CTU – Craft/test unit
DEMUX – Demultiplexer
DS1 – Digital signal level 1, transmission rate of 1.544 Mb/s (24 64-kb/s channels) in time division multiplex hierarchy
DS3 – Digital signal level 3, transmission rate of 44.736 Mb/s (672 64-kb/s channels) in time division multiplex hierarchy
E1 – European signal rate of 2.048 Mb/s (30 64-kb/s channels)
E3 – European signal rate of 34.368 Mb/s (480 64-kb/s channels)
I/O – Input/output
IAD – Integrated access device
ISDN – Integrated services digital network
LAN – Local area network
MUX – Multiplexer
PCM – Pulse-code modulated (data)
POTS – "Plain old telephone service"
—— PCM highways

Figure 11.
AnyMedia• Access System host for IAD and combined POTS/ADSL applications.

interfaces, the POTS/ADSL AP connects to the PCM highway for its voice channels, appearing to the COMDAC pack as an eight-line POTS AP (using the same assets as the POTS32 AP). For the data services, it uses the AnyMedia Access System cell-bus interface device, appearing to the AFM as an eight-line ADSL AP.

Host Digital Terminal for FITL Application.

The opportunities provided by the integrated voice and data fabric of the AnyMedia Access System become truly enabling in the new networks, where voice and data services are delivered interchangeably—sharing not only the media, but also the higher-layer functions of delivery. From the beginning, FITL architectures were proposed to bring "unlimited" bandwidth close to the customer. FITL distribution moves the subscriber line terminations (the line cards) to the proximity of the subscriber and uses optical transmission over fiber to extend the host terminal's backplane signals to the new network element—the optical network unit (ONU)—which houses the line cards. Two FITL scenarios are exemplified in Figure 1, which depicts placement of ONUs in FTTC and FTTH configurations. AnyMedia FITL solutions use the AnyMedia shelf as host, or "host digital terminal" (HDT), as illustrated in **Figure 12**. The ONU can reside a distance of up to about 11 kilometers from the HDT. Voice and data delivery to the ONUs is integrated into a common ATM transport layer, where bandwidth allocation is truly flexible between the two service categories.

To serve as an HDT for FITL, a new *optical applications pack (OAP)* asset is required for the AnyMedia Access System. The OAP interfaces with the backplane via the AnyMedia platform PCM highways for voice services (TDM format) and via the ATM BB bus for data services (ATM format). Towards the ONU, the OAP presents a 155-Mb/s ATM "pipe" connection. Although this is a SONET rate, the optical link is implemented with a single fiber, using wavelength division multiplexing (WDM) to accommodate the separate downstream (1550-nm) and upstream (1310-nm) signals. The current OAP supports two such optical ports. Depending on the application, one to four ports may be implemented.

The ONU end of the optical link terminates on a controller pack that mirrors the OAP architecture, but has a single optical port. One instance of this is the *optical-line and controller pack* developed for the "96-line" ONU intended for 30-channel markets, capable of serving up to 96 voice lines and 32 ADSL lines. The arriving cell stream is demultiplexed into narrowband (voice) and data streams, the former routed to the SAR function interfacing to the ONU's PCM highways, and the latter to a cell-bus interface.

Two AnyMedia Access System ONUs are under development. The 96-line ONU mentioned above is destined for 30-channel markets, while the ONU24 is designed to serve 24 voice lines and 12 ADSL lines for twelve to sixteen residential subscribers in the 24-channel market. The former is based on AIP assets, facilitating the reuse of AnyMedia Access System APs in the ONU. The ONU is a 9-slot AIU shelf with 1 slot dedicated to the optical-line and controller pack and 8 AP slots. The OAP used with the ONU96 is an extended version of the standard version, accessing the backplane via 2 AP slots.

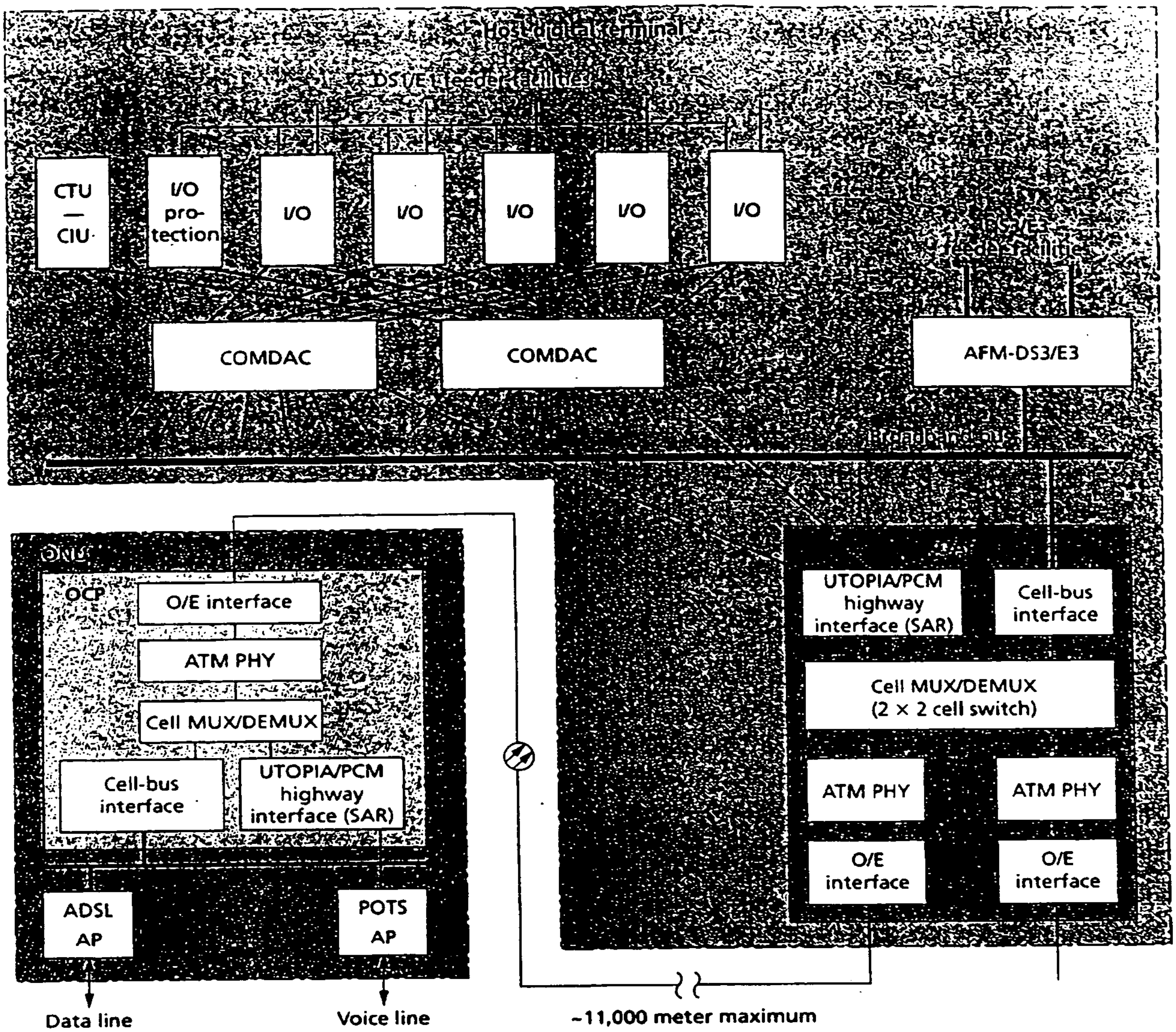
The ONU24 for the 24-channel market uses proprietary line cards optimized for the 24-channel FITL market, and is aligned with Telcordia Technologies' TA-NWT-000909[22] requirements. The two ONUs share the optical interface and associated AnyMedia assets, both hardware and software.

System Capacity and Performance

Because the modularity of APs (number of subscriber lines per pack) varies for different service categories, the maximum number of subscribers supported from a system is a function of the service categories offered (**Table I**).

With the concentrating switch interfaces (GR-303 or V5.2), dial-tone delay becomes a measure of performance for access systems due to the time required to process call requests and to set up calls. The summary requirement is that, using high-day busy-hour traffic conditions, a 768-line system must be able to perform 3615 call setups an hour, with an average delay of less than 600 ms and a maximum delay of less than 3 s for 80% of the calls. Tests performed show that the AnyMedia Access System easily meets these requirements, even under extreme load conditions.

The real-time performance of the broadband sub-



ADSL – Asymmetrical digital subscriber line
AFM – ATM feeder multiplexer
AP – Application pack
ATM – Asynchronous transfer mode
CIU – Communications interface unit
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CTU – Craft/test unit
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DS1 – Digital signal level 1, transmission rate of 1.544 Mb/s (24 64-kb/s channels) in time division multiplex hierarchy
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I/O – Input/output
MUX – Multiplexer
O/E – Optoelectronic
OAP – Optical applications pack
OCP – Optical-line and controller pack
ONU – Optical network unit
PCM – Pulse-code modulated (data)
PHY – physical layer
SAR – segmentation and reassembly
UTOPIA – Universal test and operations interface for ATM
——— PCM highways

Figure 12.
AnyMedia® Access System host digital terminal for FTTL distribution network.

Table I. System capacity in number of services supported.

Service type	Metallic access node	IAD host terminal	FITL host digital terminal
Voice and voice-grade data	512	768 (including *N*xDS0 data)	768
ISDN BRI	256	N/A	256
ADSL • Heavy • G.Lite	 60 120	 N/A N/A	 256 (30-channel) 512 (30-channel)

ADSL – Asymmetrical digital subscriber line
BRI – Basic rate interface (ISDN)
DS0 – Digital signal level 0, transmission rate of 64 kb/s (1 channel) in time division multiplex hierarchy
FITL – Fiber in the loop
IAD – Integrated access device
ISDN – Integrated services digital network

system is less critical since call setup is not a performance issue at this time, with only PVCs supported. The transmission of ATM cells over the system at a cell-loss ratio of 10^{-6} determines the system capacity. With UBR traffic (the only category supported by the first release), when transporting typical IP/ATM traffic, the AnyMedia Access System can support 360 active ADSL ports simultaneously—the maximum physically possible on a FITL system using ONU24s. This assumes an upstream peak cell rate of 768 kb/s, downstream flow control by the switch to match the feeder capacity, and not exceeding the maximum 1000 connections supported by the system. With other traffic categories being added in the coming release, the CAC algorithm will control the number of actual ADSL ports that a system can support.

Future Opportunities

In the time taken to develop the AnyMedia Access System, the access market has changed significantly—and change is expected to accelerate with the convergence of voice and data networks. The expectation is that the transport of voice services will migrate to the packet-transport networks over a period of time, with both TDM and packet-transport formats being in use for some time to come. The flexible AnyMedia Access System/AIP architecture provides significant opportunity to exploit this transitioning market. Lucent's PathStar Access Server uses AIP assets to implement an access node with an IP feeder interface for voice.[23] This product adapts the standard subscriber line connections to service networks employing "packet telephony"—that is, transmission using voice-over-IP (VoIP) protocols—by replacing the AnyMedia COMDAC packs and I/O packs with an IP COMDAC pack. The distribution fabric (PCM highways and broadband bus) is the same for both products, allowing the sharing of application packs and the AFM.

The following descriptions of future opportunities are limited to enhancements planned for the AnyMedia Access System. Including other opportunities provided by the AIP would broaden the subject beyond the scope of this paper.

APs with Service-Specific SAR Functions

The current AnyMedia Access System supports only ATM interfaces on the subscriber side. Any adaptation of other data formats must be external to it. By developing new APs with service-specific SAR functions to adapt the subscriber-side format to ATM, the AnyMedia Access System can expand the market segments it can serve. APs supporting the following service types are under consideration:

- *DS1/E1 service AP*—to serve legacy DS1 or E1 rate services (DSX-1, T1, and HDSL formats) via ATM VCs with AAL-1 (circuit emulation) format; and
- *Ethernet AP*—to provide a gateway function between local Ethernet LANs and the ATM network.

Higher-speed Integrated Feeder I/O Packs

For transmission connections to the service networks, the current AnyMedia Access System uses an external optical multiplexer for DS1 and DS3 feeder connections in remote applications. This provides flexibility to satisfy user preferences for network format and vendors. The capability to provide an integrated SONET/SDH interface with add-drop multiplexing

capability is a desired feature in some applications. The objective is to provide internal OC-3/STM-1 (155-Mb/s optical carrier) or OC-12/STM-4 (622-Mb/s optical carrier) I/O packs, which will terminate DS1/E1-carrying tributaries for telephony feeders and one or more DS3/STM-1 tributaries for data from ports connecting to unidirectional path-switched rings.

VDSL Service APs

Although currently the emphasis is on the ADSL service category (peak downstream bandwidth of 8 Mb/s), application scenarios for the delivery of very-high-speed DSL (VDSL) services are being explored. VDSL services require support for 13, 26, and, optionally, 52 Mb/s. These data rates will be required for the distribution of digital video services—high-definition television in particular. Lucent's earlier SDBAS-2000 system is already supporting such data rates, and it is expected that, with the maturing digital video market, the AnyMedia Access System will also evolve to support them. In addition to the new AP supporting VDSL line terminations, the AnyMedia shelf will be required to have supporting assets in the form of OC-3 and OC-12 rate AFMs for feeder services, with the ability to drive the second BB bus on the backplane. The use of the second bus is essential to the handling of very-high cell rate CBR-like VCs that are typical for digital video. Multicasting of these VCs is a likely requirement.

Fiber Distribution via Passive Optical Network

Lucent is currently involved with multiple demonstration projects that implement passive-optical-network (PON) access networks according to the model outlined by the Full Service Access Network[24] consortium, an international organization of operating companies. PONs allow the sharing of an optical port on an HDT by multiple ONUs (multiple subscribers)—an economic necessity for ONUs serving four or fewer subscribers. This model, also called the ATM PON, uses integrated voice and data transport in the ATM format for the links between the host and the ONUs, a feature of the AnyMedia Access System FTTL offerings. Exploratory plans for an ATM PON host call for a new PON-OAP asset for the AnyMedia Access System, with a single optical port and with a PON master multiple-access function block capable of serving sixteen ONUs. The connections from the host port to the ONUs are via a 1:16 passive optical splitter. The new ONUs' functions include the PON slave path termination function for multiple access. The sixteen ONUs connecting to the common optical port on the host share the full transport bandwidth (155 Mb/s) and can provide multiple voice lines and a data line to each subscriber. The data service will be either ADSL or HDSL rate, depending on the customer.

Summary

The AnyMedia Access System provides an integrated, flexible solution to meet a variety of network provider applications. Today's network providers must concern themselves with the economics of their networks to be competitive. By deploying equipment based on a common platform with shared assets—Lucent's Access Interface Platform—network providers can protect their investments in their networks. They need only to deploy one type of equipment to support a range of applications and distribution technologies. The AnyMedia Access System simultaneously supports both circuit-switched and packet-switched feeder interfaces, promoting network independence. So equipped, network providers will be prepared to face the access challenges posed by the ever-changing market.

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